How to estimate dental age in paleodontology?

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Abstract

Nowadays there are many methods available for dental age estimation: morphological, radiological, biochemical. Some methods require sample sectioning while other non-destructive methods are more appropriate for use in paleodontology. Children’s dental age assessment is based on phases in growth and development of the deciduous and permanent dentition, while age assessment in the adult dentition is based upon changes in the structure of hard dental tissue caused by aging. Dental age calculating software enables automated age calculations.

Keywords: Dental Age; Forensic Dentistry; Paleodontology

Bioarchaeology is the science of human remains found at archeological sites. One of the main goals is to reconstruct the lives of the people whose remains were discovered at these sites. The biggest problem is to determine the age of unidentified corpses (1). A bioarcheologist determines a subject’s age according to his/her percepiton of the level of growth, development or deterioration of various parts of the skeleton, and reaches an estimate of the "biological" or "bone" age of the person. Biological age may or may not be identical to the subject's chronological age. Bioarcheologists and forensic anthropologists determine the biological age and interpret it as a chronological age that the person would have experienced if he lived in the same conditions as a person from the sample where the standards are set. An archeologist must be able to distinguish human from animal remains and determine how many people’s remains were found at a certain site, along with the sex, age at the time of death, height, weight and race of the departed. Further research can reveal the diet and health of those studied. Environmental, social and genetic factors also influence the speed of growth and development. For example, children of lower classes develop approximately 3.0 years later than children of an equal age brought up in a higher socio-economic stratus. The main reason, according Himes, is food of poor quality and insufficient quantity. Chronic lack of protein in the diet slows the growth rate in all parts of the skeleton. The ossification centers appear later, bone growth is slower, and the epiphyses fuse with the diaphysis later than in children whose nutrition consists of high-quality food (2).

The question is which parts of the head and neck can be used during the determination of age at the time of death. By the end of 19th century researchers such as Broca, Ribbe, Schmidt, Dwight, Parsons and Box were researching skulls and found a positive correlation with age commencing with basilar suture (synchondrosis) closure at 18-21 years of age followed by observations of the vault beginning endocranially anywhere between 25 and 40 years of age and continuing through to one’s sixties. Frederic introduced a five-point rating scale (0-4) for both vault and facial sutures. Sex differences were characterized by later closure in females. Todd and Lyon used Broca's arrangement of the complication of sutures, degrees of closure, and subdivision of each suture, but followed Frederic's inverted rating scale of 0 – 4 to mark the degree of obliteration. Todd and Lyon found endocranial sutures more reliable than ectocranial sutures. Meindl and Lovejoy used a scale of 0 – 3 to judge closure at specified 1 cm sites (rather than along the entire suture) on all ectocranial sutures in 236 crania from the Hamann-Todd collection. They concluded that the lateral anterior points were more accurate than the vault sites and that race and sex didn’t influence these. They suggested that suture closure can be of value when used in conjunction with other skeletal age indicators.

Masset took a mathematical approach to this problem by tracing systematic statistical errors due to sex differences, the age structure of the reference population in relation to the unknown group, and the attraction of the middle. The attraction results from combining individual estimates into an age structure for a given population, in which case they tend to accumulate in the middle range.

A forensic dentist can be asked to assist in an investigation, since in some cases teeth are the only preserved human remains. There are several methods used in age estimation by teeth. These methods are rather accurate and reproducible (3-5).

The earliest known record of the changes in teeth used as indicators of age originates from early 19th century England where the age of seven was the limit for criminal responsibility even though children under nine years of age could not be employed in cotton, wool or saw mills; those under the age of thirteen could not work more than nine hours a day or more than 48 hours a week (6). Before 1837 there was no register of births so age could often be disputed. In 1836 professor A.T. Thomson stated that the age limit for criminal responsibility could be estimated by the eruption of “the third molar” as he called the first permanent molar erupting after the two deciduous molars (7). In 1937 dentist E. Saunders laid before the British Parliament his pamphlet titled “The Teeth a test of Age” and pointed out the value of the dentition for age assessment based on his study covering two thousand children. In 1872 C. Wedl described age-related in the permanent dentition: fatty degeneration, calcification, colloid deposits, pigment deposits in the pulp tissue, netlike atrophy, diminution of the size of the pulp cavity, increased thickness of cementum, increased translucency, attrition and color change in teeth (8). The first systematic, statistical and widely recognized approach to dental age estimation was presented by G. Gustafson in Swedish in 1947 and in English in 1950 (9). Six changes associated with age were observed on ground sections and scored on a 0-3 scale: attrition (occlusal wear), periodontosis (gingival recession), secondary dentin development within the pulp cavity, cementum apposition on the root, root resorption from the apex and transparency of the apical portion of the root. The error of estimation of this method was ±3.6 years but his research incuded only 40 anterior teeth which contributed to more favorable deviation. Gustafson's technique was first improved upon by Dalitz in 1962 and Johanson in 1971. Dalitz also limited his observations to anterior teeth but several improvements and his own five-point system generated a standard deviation in age determination of ±6 years. Johanson differentiated between seven different stages and evaluated the same six criteria as Gustafson. Johanson’s improvements are the most appreciated among forensic odontologists (3). Bang and Ramm found that root dentine seems to grow more transparent during the third decade starting at the tip of the root and advancing coronally with age and presented a new approach to age estimation in 1970. In order to simplify the method, Maples reduced the numeber of Gustafson’s dental age-related changes to 2, using only secondary dentine formation and root transparency. Solheim used five of the changes that Gustafson recommended (attrition, secondary dentin, periodontitis, cementum apposition and root transparency) and added three new changes: roughness, color and sex (13).

The first signs of human teeth can be seen in the fifth or sixth week of an embryo’s intrauterine life. Tooth buds differentiate at the site of a child’s future dental arches, which are visible on x-ray images as radiolucent areas in the upper and lower jaw. Newborns’ and children's age can be determined by the degree of mineralization (using X-ray images or tissue slides). An increment neonatal line appears on histological slides which separates hard dental tissue formed prenatally from those formed postnatally. The neonatal line is important in differentiating between newborn and stillborn babies a few days after birth. In order to see it using light microscopy, the child must live at least 3 weeks after birth, while using electronic microscopy, it is noted after one to two days of a baby’s life. During the first six months of life, age is estimated based on the degree of mineralization of babies’ teeth; during the deciduous dentition phase after the 6 month point to 2.5 years the eruption of teeth in the mouth is suitable for age estimation when population-specific reference data is available, along with an assessment of the degree of root development. Predictive sequences of tooth formation and eruption can be identified during the growth process in immature individuals. Tooth formation is a more reliable indicator of dental maturity than “eruption” or gingival emergence, and is applied in the Demirjian method, Haavikko method and several other methods for age estimation. Demirjian’s method is based on eight stages (A to H) defined from the first appearance of calcified points to the closure of the apex of seven teeth on the left side of the mandible. In his research Demirjian used the panoramic radiographs of 1446 boys and 1482 girls of French Canadian parentage. The dental maturity score was converted directly into a dental age (10). In 2009 Liversidge described a method scoring permanent mandibular teeth using 14 stages described by Moorrees and co-workers in 1963 along with an additional crypt stage and proved it to be an accurate method in estimating age using developing permanent mandibular teeth. No difference was determined between ethnicities and therefore the method could be used to estimate age in diverse ethnic groups.

Once adulthood is reached, age manifestation in adults is much less obvious, which makes age determination more difficult and the accuracy of most morphological methods is significantly reduced. The formulae used for age estimation in adults are mostly accurate for adults between 40 and 50 years of age, while the inaccuracy increases below and above that age bracket. Age estimation can be determined by the degree of tooth wear using several systems for scoring of the rate of attrition. Tooth wear has been associated with age since 1897 when Broca introduced the five-stage scale. In the 20th century several improved systems were developed by Gustafson (1950), Murphy (1959), Helm and Prdyso (1979), Brothwell (1981) and Lovejoy (1985). Not all teeth succumb to wear at the same rate throughout life and a number of studies have shown that tooth wear patterns and rates vary widely among different populations. The rate of attrition is determined by a complex set of factors related to the lifestyle of the study population and its genetic background. Therefore, it is necessary to develop a standard specific to a population in order to estimate age more precisely. Differences between the sexes may vary from nonexistent to slight but not statistically significant. However, there are some indications that male teeth are worn quicker than female teeth and it may be due to greater food consumption in males than in females. This method is not effective past age 50 (Miles, 1958). Recently, the causes of attrition have involved other factors such as bruxism, diet and environment. Age estimation by examining the degree of dental attrition has its weakness and limitations and should not be used as the sole indicator of age.

Samples used for dental age assessment in paleodontological research usually involve teeth, jaws and skulls from collections of human skeletal remains originating from different sites, stored in museums and institutes. As destructive methods involve taking a sample from the object of interest, thus undermining the integrity of the sample, for example by sectioning teeth, destructive methods should be avoided in determining the age of such remains. Non-destructive methods conserve the integrity of the subject. It is possible to achieve reasonably accurate dental age estimation using both destructive and non-destructive methods when techniques are applied appropriately.

Tooth color can also be used as an indicator of age. Ten Cate et al. reported that almost all teeth were estimated within ±10 years of chronological age using root dentin color as the indicator (19). Color was found to be more related to age than most commonly used dental age-related changes and it is recommended that tooth color is included in multiple regression methods for age calculation (20).

Dental radiographs are used for estimating age in situations when tooth destruction and extraction is not permitted. Kvaal and Solheim (1994) found that the reduction in the size of the pulp cavity as a result of secondary dentine deposits can be measured on radiographs and used as an indicator of age. They also presented a method involving combined radiological and morphological measurements. The strongest correlation with age was in the ratio between the width of the pulp and the root. However, the correlation between age and the ratios between pulp and the root length was only significant in maxillary cuspids and premolars (14). In 1995 Kvaal proposed a method based solely upon the measurements performed on periapical radiographs, a method easily employed when the preservation of the research material is requested. Bosmans el al. (2005) applied the original formulae from Kvaal's technique (1995) using measurements made on panoramic radiographs instead of the typical periapical radiographs originally described. The age estimations were comparable to those based on the original technique (Kvaal and Solheim, 1994; Bosmans et al, 2005; Stavrianos et al., 2008). (3, 18) In 2006 Yang et al. used cone-beam CT scanning to acquire the 3D images of teeth in living individuals and calculated the ratio of pulp/tooth volume. (22) Age estimation based on the pulp/tooth volume ratio generates promising results.

It is possible to calculate age using software developed for automated dental age calculation (17). The software is based on the most accurate and frequently referenced morphological and radiological techniques which demand the extensive calculations done by Bang and Ramm (1970), Johanson (1971), Solheim (1993), Kvaal and Solheim (1994) and Kvaal (1995). After measuring the required parameters and entering these values into the calculator, an automatic calculating process begins - calculating errors are avoided.

Table 1. Recommended dental age estimation procedures in adults according to American Society of Forensic Odontology (2007) (3)

Status	Examination type	Specific techniques or methods
Living	Radiographs/Morphological	Kvaal and Solheim (dental radiographs)
	Post-Formation Changes	Johanson Sectioning
	Post-Formation Changes	Lamendin *et al. (1992)*
	Post-Formation Changes	Bang and Ramm
Deceased	Biochemical	Aspartic Acid Racemization
Anthropological/Historical Collections		
Skeletal	Non-destructive	Kvaal/Solheim Intact Methods

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